EPRI

technical brief

Test Report for New AVR/UPS

Customer Power Conditioning Solutions Target
Science & Technology Development

Introduction

In a collaboration with a company in the power quality industry, EPRI has developed the concept of a hybrid adjustable voltage regulator/uninterruptible power supply (AVR/UPS) system that provides unique power line conditioning capabilities to end users. Most uninterruptible power supply (UPS) systems today provide uninterrupted power to a user's critical load in case the input power is out of specified tolerances. There are three typical approaches to UPS implementation. The first is an on-line UPS, which uses double conversion and provides regulated voltage to the load over a specified range of input line fluctuations, and also provides back-up power from a battery when the input power goes out of tolerance. The second approach, referred to as a stand-by UPS, provides line power directly to the load when it is within tolerance, and provides back-up power when the utility voltage is out of tolerance. This is typically the least expensive realization of a UPS. However, it does not provide any level of voltage regulation to the load. The third approach is a line interactive UPS, wherein the incoming utility voltage is regulated and is then supplied to the load. Battery power is only utilized when the utility voltage is out of the unit's ability to regulate voltage.

Examining commercially available UPS equipment, it is clearly evident that the rating of the UPS and the duration of battery back-up are the primary elements determining cost. The battery back-up function tends to be very expensive, and it is not cost effective to apply uninterruptible power to non-critical loads, which are still sensitive to voltage fluctuations. It is also evident that non-critical but sensitive loads in many locations tend to be three to four times the rating of the critical loads. There are presently no integrated solutions available to users in the U.S. and overseas that provide separate voltage regulation and UPS function to distinct loads from one power line conditioner. However, several manufacturers seem to be moving in the direction of "multi-functional" UPS systems, wherein a given unit provides varied power line conditioning functions, including a back-up power function for only part of the total load. One recent example of a multi-functional UPS unit in the U.S. is the Back-UPS product from American Power Conversion which provides simple spike suppression to the majority of the load, and a back-up UPS function to partitioned priority load, via segmented outlet points in the same unit. This indicates that there should be very high acceptability in the U.S. for a unit which packages a UPS and a voltage regulator for a larger load in the same package. Such a product concept also has very strong appeal to users in developing countries, where the need for such a product is extremely high, and the market potential of such a product is vast.

A new concept has been developed which utilizes a voltage regulator and battery module to provide multiple functions to the end user. Combined together the modules have components that make it competitive with typical UPS solutions which provide back up power to 1 kW of priority load. What is unique about the concept product is that the same unit also provides compensation against voltage sags for up to 4 kW of sensitive load. The voltage regulator module can also be sold as a stand-alone unit that provides 4 kW of line voltage regulation. Compared with commercially available voltage regulators, this new design is smaller in size, cost competitive and very robust.

Principle of Operation

At the heart of the AVR/UPS is a series transformer coupled voltage regulator device, as shown in Figure 1. The load is partitioned into two parts, the sensitive load and the priority load. For nominal line input voltage, the AVR/UPS is in bypass mode. The voltage across the transformer is held to zero and the utility feeds both the sensitive and priority loads. During a voltage sag or a sustained brownout down to 75% of nominal line voltage, the unit operates in adjustable voltage regulation mode. A dc/ac inverter is inserted in series with the utility voltage, and provides a regulated sinusoidal output voltage to both the sensitive and priority loads. Upon sensing a complete outage, the sensitive load gets reconnected to the input ac line, while the priority load is supplied back-up

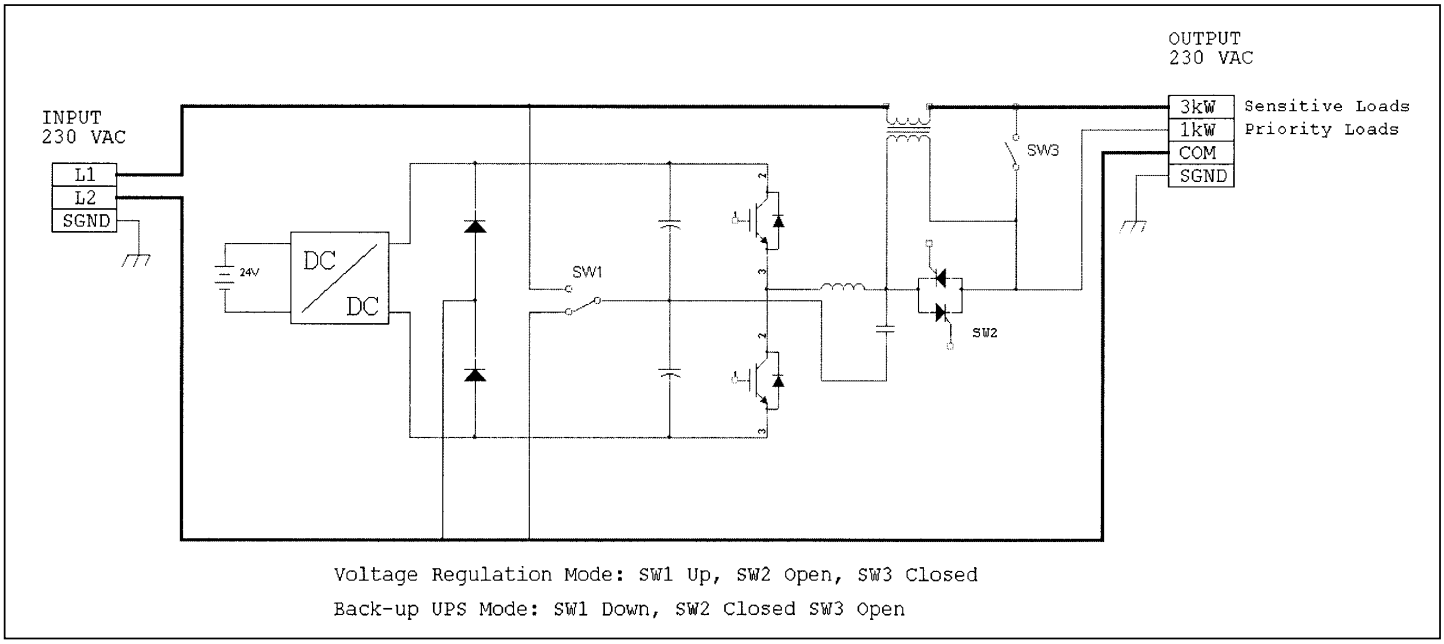

Figure 1. 4 kW Automatic Voltage Regulator/Uninterruptible Power Supply.

power from the battery through the inverter. In this mode, the output voltage supplied to the priority load is sinusoidal.

Using a patent pending topology, the AVR/UPS allows the same inverter to perform both the voltage regulation and back-up power functions. This allows packaging a 4 kVA voltage regulator function with a 1 kVA UPS function in a cabinet which is comparable in size with a 1 kVA UPS, and is smaller in size than adjustable voltage regulators (AVR), such as constant voltage transformers, rated at 4 kVA. For instance, a 4 kVA AVR integrated with a 1 kVA UPS prototype has been built, and is shown in Figure 4. The unit dimensions are 9 in. x 9 in. x 16 in., with a ride-through time of three to five minutes in battery back-up mode. This is much smaller than a typical 4 kVA voltage regulator and comparable with a commercially available 1 kVA UPS. Further, it is projected that the units, in volume production, will be lower cost than the 4 kVA voltage regulator, and comparable in cost with a sinusoidal output 1 kVA UPS with similar ride-through capability.

The basic circuit schematic in voltage regulator mode and the back-up mode is shown in Figure 1. When the input voltage is within nominal limits, the voltage across the series transformer is held to zero, effectively passing the utility voltage through to both the sensitive and priority loads. It can be seen that in voltage regulator mode, the inverter is effectively connected in series with the utility source, providing a regulated output voltage to both the sensitive and priority load. When the input voltage drops below a defined threshold, the unit goes into back-up power mode. In this mode, the series transformer is shorted which reconnects the sensitive load to the input ac line and connects the priority load to the inverter. A battery contained inside the unit provides back-up power to the inverter. The run-time in this mode depends on the capacity and state-of-charge of the battery. The inverter uses insulated gate bipolar transistors (IGBTs) and operates under pulse width modulation (PWM) control to provide sinusoidal output voltage at the output in both modes of operation.

Test Results

Figures 2a through 2c show waveforms depicting operation of the AVR/UPS prototype under various line conditions. Expanded waveforms of the unit's output in voltage regulation mode are shown in figures 2a and 2b. Figure 2c shows the sinusoidal output of the unit's in back-up power mode. Figure 3a shows transition from voltage regulation mode to back-up power mode under a full resistive load. Figure 3b shows the output of the unit in voltage regulation mode during an extended voltage sag. The mode transitions occur in less than 1 cycle, adequate for most back-up power applications. Faster transitions are possible, but would cost more to implement.

The unit has been extensively tested in the laboratory, and is targeted for testing at a utility customer site in 1999. Test data indicate efficiency of 99% in normal utility mode, and 98% in voltage regulate mode. Input current distortion is low, with an input power factor of 0.97 with a resistive load. The battery would be sized for the amount of storage required.

Applications

The AVR/UPS product has good potential in various applications. For instance, in an office situation this product will allow protection of all office equipment against brownouts and sags, with protection of the server and other critical equipment against longer duration outages. Similarly, for protecting medical equipment, the AVR section protects all the equipment in a room, while providing back-up power for special equipment requiring uninterrupted operation. It should be noted that this equipment is not targeted for life support equipment back-up.

Another important potential market for the AVR/UPS is in developing countries where power quality is poor. Utility voltage regulation is poor, with frequent and extended brownouts, and blackouts that last for 1 to 2 hours at a time. Many customers in enclosed office and shopping centers, as well as residential customers in high rise buildings cannot use back-up generators, and have to install voltage regulators to protect all their sensitive loads. In such a case, the AVR/UPS

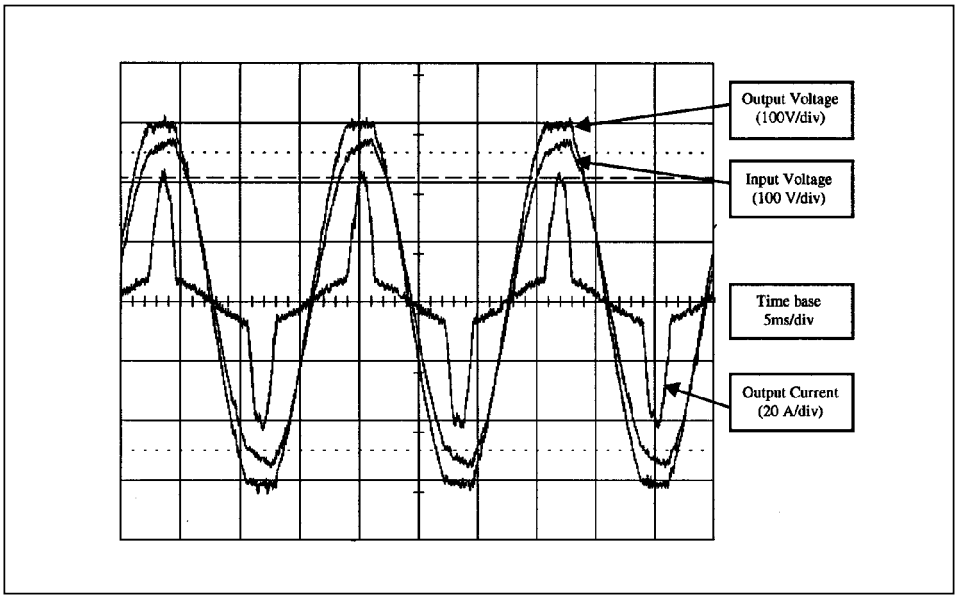

Figure 2a. 4 kW Sinusoidal output voltage waveform in AVR mode with a crest factor load.

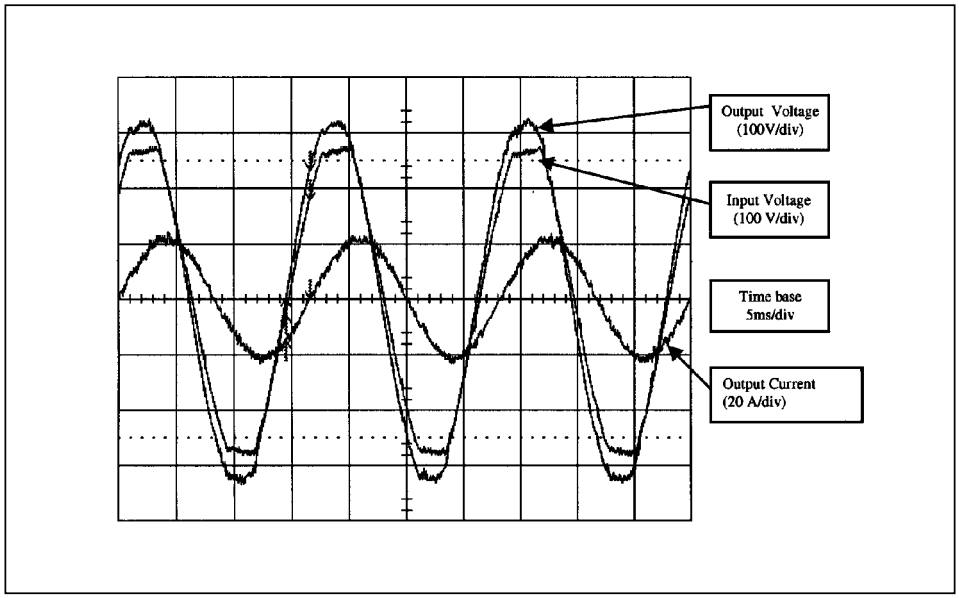

Figure 2b. Sinusoidal output voltage waveform in AVR mode with an inductive load.

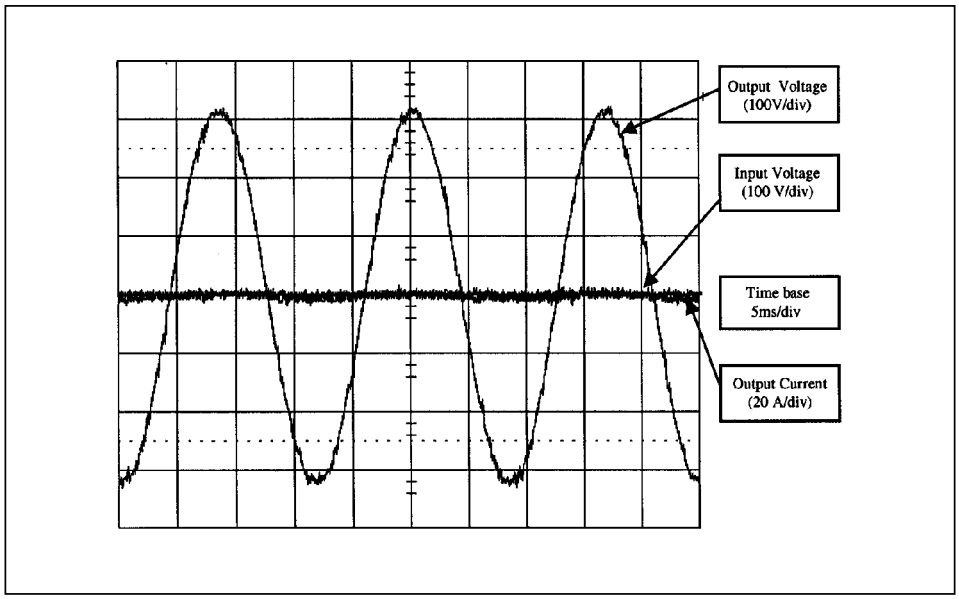

Figure 2c. Sinusoidal output voltage waveform in UPS mode with a light resistive load.

provides an ideal solution, with voltage regulation for the entire shop, office or residential load, and back-up power for part of the load. For instance, in a commercial small business situation, the AVR/UPS could provide regulated voltage for the entire store, and back-up power for the cash registers and some lights. For residential use, the AVR/UPS could regulate the voltage for all sensitive appliances such as the refrigerator, stereo, television, computers and some lights, and could provide back-up power for priority loads such as restricted lights and the television. Back-up power could be extended to the one to two hour range through the use of add-on battery modules.

The AVR/UPS provides new functionality and a new price-performance point in the area of power line conditioning and back-up power. It is targeted at meeting multiple functions of voltage regulation for a larger sensitive load (for example 4 kW), and back-up power for a portion of that load, i.e., the priority load (for example 1 kW). The AVR/UPS potentially meets a price that is lower than existing voltage regulators rated for the sensitive load, and is price comparable with existing UPS systems rated for the priority load.

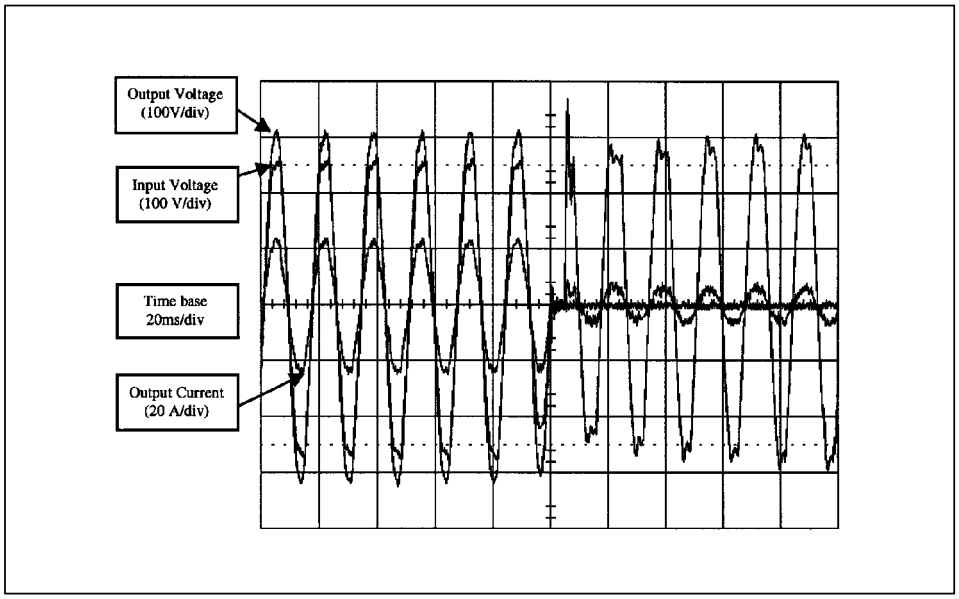

Figure 3a. Transfer from AVR (4 kW) to UPS (1 kW) mode with full resistive load.

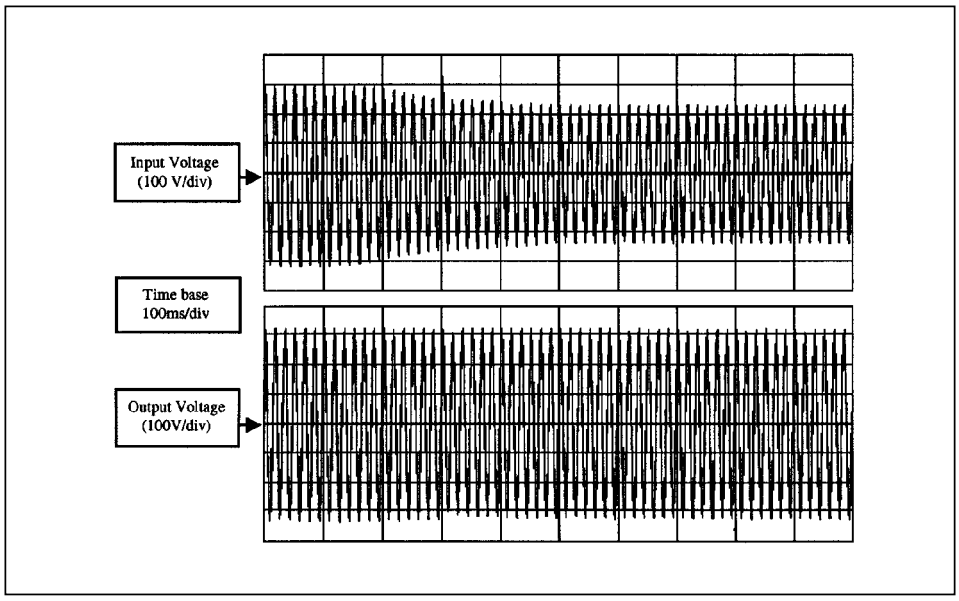

Figure 3b. Sinusoidal output voltage waveform in UPS mode with a light resistive load.

Figure 4. 4kW Automatic Voltage Regulator/ Uninterruptible Power Supply

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